AD-A212 082

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION: Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S): M65-89	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION: U.S. Army Rsch Inst of Env Med; 6b. OFFICE SYMBOL (If applicable): SGRD-UE-MEB	7a. NAME OF MONITORING ORGANIZATION: U.S. Army Rsch Inst of Env Med
6c. ADDRESS (City, State, and ZIP Code): Natick, MA 01760-5007	7b. ADDRESS (City, State, and ZIP Code): Natick, MA 01760-5007
8a. NAME OF FUNDING/SPONSORING ORGANIZATION: Same as 6a.; 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code): Same as 6c.	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. —; PROJECT NO. 3E1627 87A878; TASK NO. 878/AE; WORK UNIT ACCESSION NO 084

ELECTE SEP 0 8 1989

DTIC FILE COPY

11. TITLE (Include Security Classification)

(U) Air Velocity Mapping of Environmental Test Chambers

12. PERSONAL AUTHOR(S)

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13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Presentation	FROM ____ TO ____	July 1989	24

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	air velocity mapping; anemometer tree system; environmental chamber

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

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(EDC)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL: Stephen KW. Chang, Ph.D.	22b. TELEPHONE (Include Area Code): 508/651-4817; 22c. OFFICE SYMBOL: SGRD-UE-MEB

DD Form 1473, JUN 86 Previous editions are obsolete. SECURITY CLASSIFICATION OF THIS PAGE

89 9 06 125

AIR VELOCITY MAPPING OF ENVIRONMENTAL TEST CHAMBERS

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The air velocity profile of the U. S. Army Research Institute of Environmental Medicine articulated manikin chamber was mapped using an anemometer tree system. It was found that the air velocity within the chamber was a disparate property. Air velocities were significantly different at different chamber fan speed settings, and at different heights in the chamber. Airflow patterns in such an environmental chamber are an inherent function of conventional chamber construction, but influenced by external factors such as equipment situated within the chamber. The practice of employing a single thermal or cup anemometer to monitor chamber air velocity is, in general, ~~totally~~ inadequate.

Keywords: air velocity mapping, anemometer tree system, environmental chamber

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The air velocity profile of the U. S. Army Research Institute of Environmental Medicine articulated manikin chamber was mapped using an anemometer tree system. It was found that the air velocity within the chamber was a disparate property. Air velocities were significantly different at different chamber fan speed settings, and at different heights in the chamber. Airflow patterns in such an environmental chamber are an inherent function of conventional chamber construction, but influenced by external factors such as equipment situated within the chamber. The practice of employing a single thermal or cup anemometer to monitor chamber air velocity is, in general, totally inadequate.

INTRODUCTION

Air velocity is one of the basic physical quantities that defines the thermal environment [ISO International Standard 7726, 1985]. In the HVAC field, air velocity is an important environmental variable that must be measured for the evaluations of the air diffusion performance index (ADPI), or the thermal comfort indices such as predicted mean vote (PMV) or predicted percentage of dissatisfied

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(PPD) [ISO International Standard 7730, 1984]. Air velocity also serves an critical role in the determination of biophysical parameters such as convective heat transfer and evaporation heat loss.

Since environmental chambers provide proper control for simulation of various conditions, they are often relied upon to provide the desired air velocity environment. However, air velocity profiles within a test chamber are, in general, not currently available. In many test chambers, the air velocity is assumed to be uniform throughout, and a single thermal or cup anemometer is used to monitor the air velocity for the entire chamber. The uniform air velocity assumption is incorrect and the practice of using a single anemometer is totally inadequate. This present study reports on a technique to validate the air velocity scenarios within a chamber. The U. S. Army Research Institute of Environmental Medicine (USARIEM) articulated manikin chamber was chosen and used as an example. A multi-anemometer system, the anemometer tree (Figure 1), was used to map the air velocity profile of the chamber.

METHOD

The articulated manikin chamber was cleared of all articles except the articulated manikin and its supporting frame. Figure 2 is a schematic representation of the articulated manikin chamber. The chamber floor is represented by a rectangle. Direction of airflow is from right to left. On the chamber floor, each anemometer tree placement location is designated by a '●' symbol. The human figure represents the position of the articulated manikin. The approximate position of the manikin supporting frame cage is also shown (inset).

The chamber temperature was set at 27°C. Chamber fan speeds were set to 20%, 40%, 60% and 80% of maximum fan speed. These four settings provided chamber air velocity ranges between 0.2 m/s to 2.5 m/s. On the anemometer tree stack (see Figure 1), six omnidirectional thermal anemometers (range 0 - 3 m/s) were positioned, each at a different height level. The distance between each anemometer probe was 30cm, with the lowest probe 30cm above the chamber floor. The highest probe was therefore 180cm above ground. The 30cm and 180cm levels corresponded approximately to the ankle and the head positions, respectively, of the articulated manikin.

Figure 3 shows the placements (●) of the anemometer tree within the chamber. In Figure 3, the row designation of A, B, C, D, and E and the column number 1, 2, 3, 4, and 5 help to identify each tree placement location. The anemometer tree was first placed at the A1 location in the chamber. Chamber fan speed was set to 20% and air velocity measured. The chamber fan speed was then increased to the next level for the next measurement. After all four wind speeds (20%, 40%, 60%, and 80%) were completed, the anemometer tree was then moved to another location, to begin another round of measurement. The sequence of anemometer tree placement was A1, A2, A3, A4, A5, B1, B2, ... B5, C1, ... C5, D1, ... D5, E1, ... E5.

Wind speed data were collected using a portable computer. The thermal anemometer signal was converted through a analog-to-digital (A/D) converter to digital data. The digital data were then sampled and stored in the computer. At each tree location, for each chamber fan speed setting, the anemometer data

were collected continuously over a thirty minute period. The measured air velocity shown in Tables 1-4 represent the average of the 30 minute period. With twenty-five tree placements, each at four different chamber wind speed, a total of 100 sets of air velocity profile data were collected.

RESULTS

The entire set of the measured anemometer data are included as Tables 1 through 4. Tables 1, 2, 3 and 4 contain, respectively, the air velocity data at 20%, 40%, 60% and 80% of maximum chamber fan speed. The anemometer tree locations are designated using row A, B, C, D, and E, and column 1, 2, 3, 4, and 5 (refer to Figure 3). The air velocity profiles are plotted in three dimensional maps, shown in Figures 5 through 10. Figure 4 is used as an example to explain the air velocity maps. The manikin figure, while shown in Figure 4, is deleted in most plots to provide a clearer background for the air velocity plot. The level label (120 cm) indicates the height level of the anemometers. The air velocity data are mapped in a grid plot. The grid in Figure 4 represents the air velocity map from anemometer measurement at the 120 cm level (at 80% fan speed). If the air velocity of a particular level is fairly uniform, then a flat grid is the result. An uneven grid map indicates large variations in the air velocity pattern. The maximum and minimum air velocity values for the data set represented in the grid are also displayed to show the range.

Figures 5 - 10 display the full set of air velocity data contained in Tables 1 - 4. Each of the six figures represent one anemometer height level. Within each

Figure, four plots <a>, <b>, <c>, and <d> are derived from the four fan speed settings 20%, 40%, 60%, and 80%, respectively.

DISCUSSIONS

Several observations can be made from Figures 5 - 10. One immediately apparent (and implicit) is that the variation in air velocity was much more pronounced at higher fan speed than at lower fan speed. Plots <a> in Figures 5-10 show at 20% fan speed, air velocity was nearly uniform throughout the chamber, at all height levels. In contrast, plots <d> of Figures 5-10 displayed large variation in air velocity when 80% chamber fan speed was employed. It should be mentioned that the 20% fan speed is the minimal air circulation required to maintain chamber air temperature regulation.

The second observation is that, as expected, structures within the chamber altered the airflow pattern significantly. This includes all test equipment used in the chamber and other build-in structures and constructions within the chamber. In this particular testing chamber, the articulated manikin was the most prominent structure. In Figure 8, at 120 cm, it can be seen that air velocity decreased not only behind but also in front of the manikin. In comparison to Figure 10, where the anemometer height (180 cm) was slightly above the head of the manikin, interference of the airflow was much less noticeable.

There were also variations in the air velocity maps which are not as easily explained. In Figure 9, plot <d>, aside from the well around the manikin, there were two other dips in the air velocity grid: at positions B2 and D3 (refer to Figure 3 for position designation). Also, depressions at positions B2 and E2 in

Figure 8<d>, and at positions B2 and D4 in Figure 7<d>, were evident. These decreases might be caused by the manikin supporting frame, although the evidence was not conclusive. If the supporting frame was the culprit, symmetrical effects should have been found, i.e. the depression at B2 should have coupled with another dip at D2, since the frame is symmetrical about the manikin. No symmetry was evident, and no conclusion can be made. Conversely, there were also regions of high air velocity, such as at position C3 in Figure 7<d>, and along the C2-D2 ridge in Figures 9<c> and 9<d>, which are equally as difficult to interpret. Nevertheless, these variations must be accepted as inherent to this particular chamber construction, and their effects must be properly considered when using such a chamber design.

In a recent study in another environmental chamber, the USARIEM High Elevation Simulation Facility (altitude chamber), we also noticed that not only does the chamber exhibit a characteristic air velocity pattern but also variants in airflow can be attributed to different simulated elevations. For example, during the ascending and descending phases to a simulated hypobaric environment, air velocity showed marked variations during a transient period before slowly stabilizing to a new characteristic pattern of the new chamber environment.

It seems clear that no environmental chamber should be assumed to exhibit a laminar or uniform flow pattern. Each individual chamber has its own inherent air velocity profile, perhaps due to its construction, and the profile invariably changes as the chamber condition is altered. The impact of asymmetrical airflow patterns undoubtedly affect human thermal comfort votes. The standardized

technique described in this report could be easily employed prior to or along with specific studies requiring precise air velocity data, and coupled with human thermal comfort surveys.

CONCLUSION

The USARIEM articulated manikin chamber air velocity profile was mapped using an anemometer tree system. It was found that the air velocity within the chamber was far from uniform, and the airflow patterns could be significantly different at different chamber fan speed setting. As expected, equipment and structure within the chamber did alter the airflow pattern. Furthermore, there were also variations in the air velocity which were apparently inherent to the chamber construction itself, but could not otherwise be explained. The assumption of uniform airflow within a chamber is inaccurate and the practice of employing a single anemometer to monitor the chamber air velocity is wholly inadequate. The air velocity profile of given chamber should be mapped for all studies or thermal surveys in which air velocities or precise heat transfer parameters are important.

REFERENCES

ISO International Standard 7726, 1985. "Thermal environments - instruments and methods for measuring physical quantities." International Organization for Standardization.

ISO International Standard 7730, 1984. "Moderate thermal environments - determination of the PMV and PPD indices and specification of the conditions for thermal comfort." International Organization for Standardization.

Table 1

Air velocity data (m/s) at 20% maximum fan speed

refer to Figure 3 for anemometer location designation

20% maximum fan speed

Anemometer Probe Height						
180cm	150cm	120cm	90cm	60cm	30cm	Anemometer Location
0.226	0.239	0.264	0.235	0.295	0.274	A1
0.274	0.264	0.343	0.314	0.375	0.327	A2
0.287	0.286	0.349	0.348	0.346	0.348	A3
0.302	0.246	0.336	0.325	0.366	0.317	A4
0.258	0.272	0.322	0.350	0.336	0.364	A5
0.325	0.254	0.349	0.339	0.361	0.334	B1
0.287	0.151	0.238	0.164	0.287	0.229	B2
0.183	0.126	0.249	0.205	0.311	0.264	B3
0.225	0.169	0.184	0.245	0.295	0.265	B4
0.201	0.194	0.113	0.187	0.241	0.260	B5
0.307	0.246	0.302	0.247	0.288	0.215	C1
0.298	0.241	0.285	0.234	0.286	0.199	C2
0.252	0.250	0.304	0.301	0.340	0.249	C3
0.237	0.148	0.216	0.208	0.280	0.210	C4
0.178	0.110	0.070	0.210	0.163	0.221	C5
0.258	0.270	0.305	0.291	0.303	0.305	D1
0.283	0.207	0.242	0.180	0.262	0.229	D2
0.268	0.060	0.249	0.105	0.107	0.100	D3
0.205	0.177	0.185	0.095	0.105	0.148	D4
0.256	0.089	0.165	0.166	0.166	0.167	D5
0.163	0.169	0.194	0.230	0.321	0.357	E1
0.172	0.183	0.231	0.313	0.409	0.428	E2
0.259	0.342	0.402	0.406	0.385	0.408	E3
0.257	0.387	0.385	0.299	0.263	0.262	E4
0.288	0.288	0.284	0.262	0.227	0.217	E5

Table 2

Air velocity data (m/s) at 40% maximum fan speed

refer to Figure 3 for anemometer location designation

40% maximum fan speed

Anemometer Probe Height						
180cm	150cm	120cm	90cm	60cm	30cm	Anemometer Location
0.609	0.579	0.670	0.550	0.818	0.671	A1
0.737	0.689	0.876	0.798	0.969	0.847	A2
0.765	0.658	0.883	0.837	0.942	0.821	A3
0.796	0.646	0.867	0.836	0.918	0.812	A4
0.748	0.624	0.799	0.804	0.816	0.802	A5
0.768	0.535	0.825	0.722	0.878	0.645	B1
0.715	0.391	0.527	0.365	0.661	0.504	B2
0.539	0.279	0.619	0.497	0.787	0.599	B3
0.430	0.345	0.381	0.462	0.758	0.540	B4
0.415	0.495	0.274	0.490	0.583	0.551	B5
0.756	0.592	0.705	0.615	0.833	0.526	C1
0.760	0.681	0.653	0.626	0.922	0.585	C2
0.762	0.411	0.693	0.719	0.906	0.560	C3
0.584	0.370	0.480	0.542	0.752	0.495	C4
0.432	0.195	0.211	0.479	0.391	0.503	C5
0.649	0.627	0.707	0.611	0.823	0.731	D1
0.800	0.590	0.657	0.557	0.686	0.576	D2
0.660	0.188	0.608	0.367	0.638	0.270	D3
0.613	0.310	0.461	0.307	0.496	0.413	D4
0.584	0.307	0.514	0.483	0.563	0.498	D5
0.376	0.501	0.420	0.407	0.555	0.519	E1
0.486	0.506	0.371	0.351	0.507	0.544	E2
0.596	0.780	0.664	0.548	0.723	0.811	E3
0.528	0.980	0.880	0.729	0.744	0.760	E4
0.554	0.834	0.808	0.669	0.649	0.627	E5

Table 3

Air velocity data (m/s) at 60% maximum fan speed

refer to Figure 3 for anemometer location designation

60% maximum fan speed

Anemometer Probe Height						
180cm	150cm	120cm	90cm	60cm	30cm	Anemometer Location
1.262	1.096	1.255	1.063	1.625	1.245	A1
1.513	1.365	1.655	1.553	1.896	1.539	A2
1.556	1.303	1.676	1.630	1.789	1.515	A3
1.546	1.324	1.658	1.621	1.707	1.451	A4
1.366	1.258	1.553	1.533	1.458	1.408	A5
1.402	0.996	1.547	1.301	1.579	1.139	B1
1.452	0.724	1.004	0.698	1.264	0.965	B2
1.094	0.558	1.223	1.049	1.602	1.098	B3
0.849	0.740	0.696	0.920	1.562	1.001	B4
0.698	0.978	0.489	0.974	1.127	0.974	B5
1.530	1.229	1.360	1.242	1.760	1.057	C1
1.597	1.395	1.288	1.253	1.909	1.185	C2
1.531	0.799	1.379	1.410	1.712	1.048	C3
1.107	0.642	0.956	1.028	1.451	0.862	C4
0.852	0.379	0.359	0.911	0.805	0.934	C5
1.280	1.251	1.320	1.282	1.470	1.281	D1
1.628	1.276	1.288	1.185	1.309	1.115	D2
1.378	0.358	1.214	0.759	1.304	0.575	D3
1.275	0.574	0.883	0.630	1.029	0.863	D4
1.133	0.532	0.989	0.884	1.082	0.942	D5
0.591	0.764	0.659	0.614	0.960	0.811	E1
0.699	0.721	0.595	0.531	0.740	0.718	E2
1.034	1.210	1.080	0.853	1.017	1.140	E3
0.837	1.536	1.444	1.132	1.197	1.297	E4
0.924	1.599	1.514	1.233	1.162	1.174	E5

Table 4

Air velocity data (m/s) at 80% maximun fan speed

refer to Figure 3 for anemometer location designation

80% maximum fan speed

Anemometer Probe Height						
180cm	150cm	120cm	90cm	60cm	30cm	Anemometer Location
1.945	1.592	1.845	1.590	2.394	1.766	A1
2.299	2.032	2.400	2.287	2.804	2.170	A2
2.287	2.047	2.431	2.406	2.625	2.026	A3
2.210	2.019	2.359	2.360	2.395	1.981	A4
1.969	1.938	2.305	2.263	2.048	1.933	A5
2.087	1.548	2.295	1.879	2.293	1.609	B1
2.227	1.067	1.470	1.041	1.856	1.418	B2
1.711	0.845	1.852	1.623	2.359	1.590	B3
1.288	1.147	1.039	1.463	2.412	1.383	B4
0.975	1.456	0.734	1.512	1.665	1.291	B5
2.327	1.880	2.042	1.880	2.569	1.589	C1
2.467	2.130	2.086	1.965	2.832	1.842	C2
2.329	1.264	2.163	2.131	2.576	1.579	C3
1.556	0.943	1.524	1.574	2.229	1.305	C4
1.274	0.536	0.519	1.429	1.224	1.371	C5
1.974	1.971	1.996	1.972	2.054	1.810	D1
2.460	2.005	1.961	1.752	1.844	1.650	D2
2.166	0.545	1.884	1.205	1.928	0.837	D3
1.918	0.893	1.365	0.993	1.499	1.268	D4
1.630	0.852	1.397	1.301	1.585	1.355	D5
0.786	0.986	0.933	0.812	1.364	1.155	E1
0.962	0.932	0.785	0.737	0.985	1.013	E2
1.499	1.669	1.493	1.148	1.422	1.542	E3
1.137	2.090	1.909	1.517	1.673	1.846	E4
1.375	2.298	2.181	1.756	1.644	1.689	E5

Figure Caption Sheet

Figure 1 Anemometer tree

Figure 2 Schematic representation of the articulated manikin chamber and supporting frame cage

Figure 3 Articulated manikin chamber diagram
anemometer tree placement location (●)
direction of airflow is from right to left

Figure 4 Illustration of air velocity map (120cm height level)

Figure 5 Air velocity map at 30cm height level, schematic of manikin included

Figure 6 Air velocity map at 60cm height level, schematic of manikin removed

Figure 7 Air velocity map at 90cm height level, schematic of manikin removed

Figure 8 Air velocity map at 120cm height level, schematic of manikin removed

Figure 9 Air velocity map at 150cm height level, schematic of manikin removed

Figure 10 Air velocity map at 180cm height level, schematic of manikin included

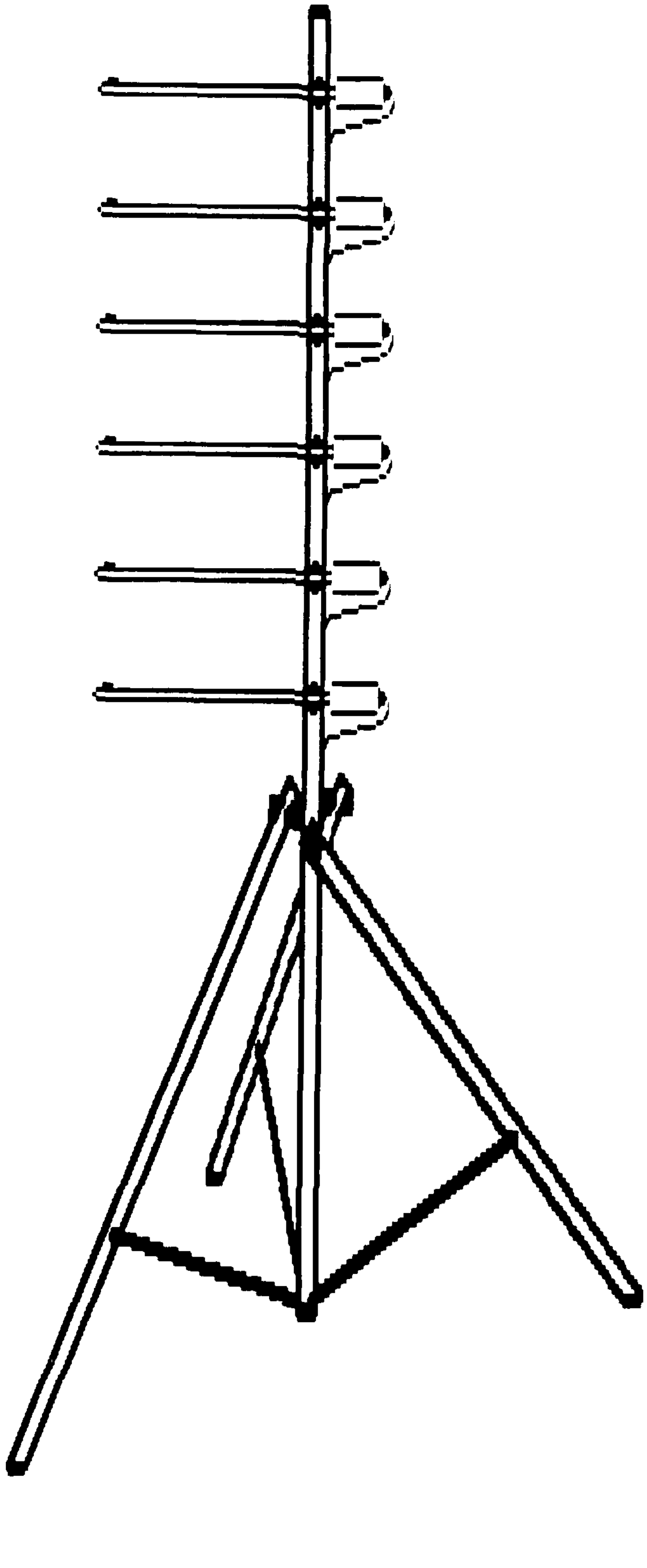
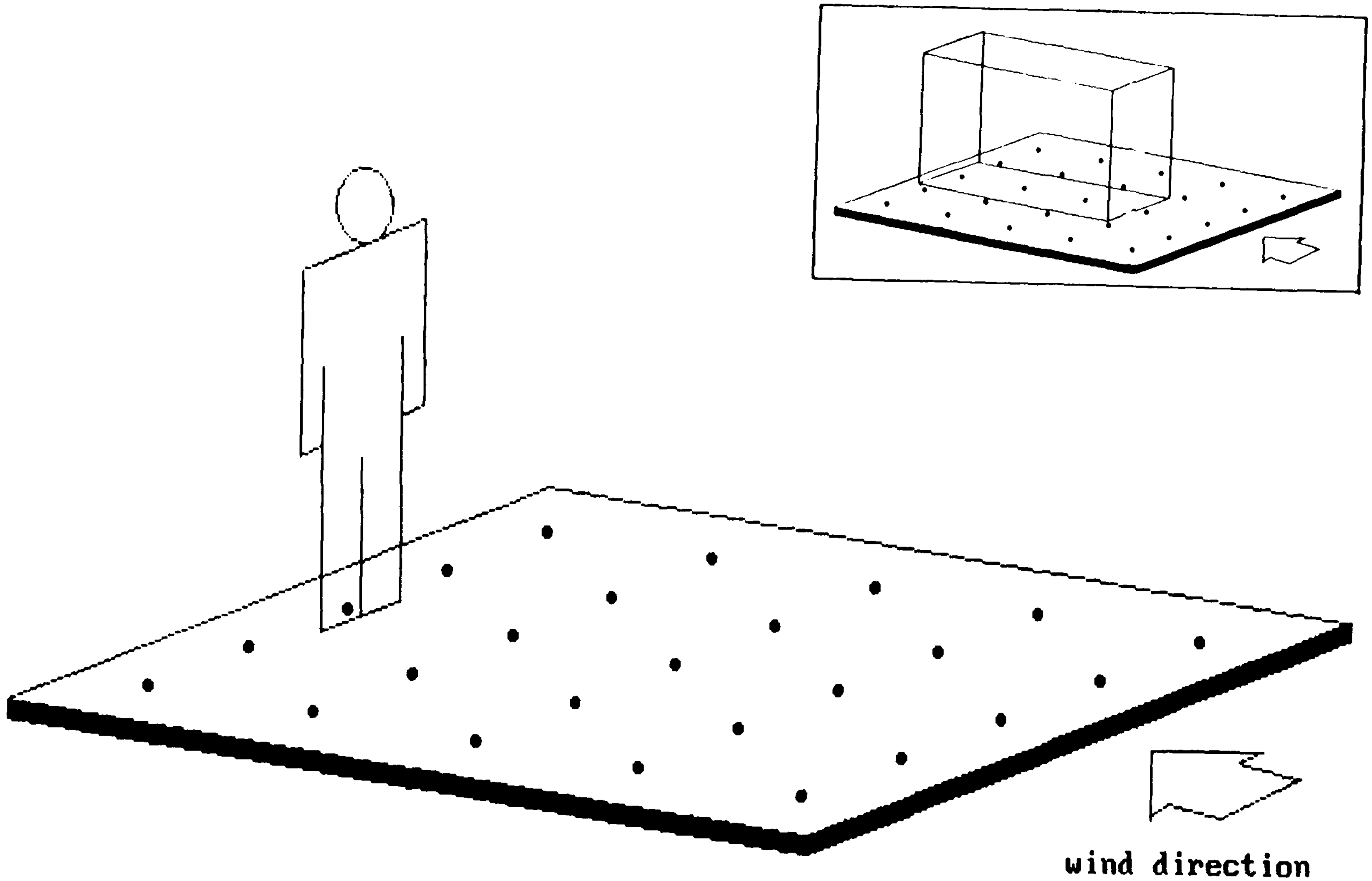


Figure 1



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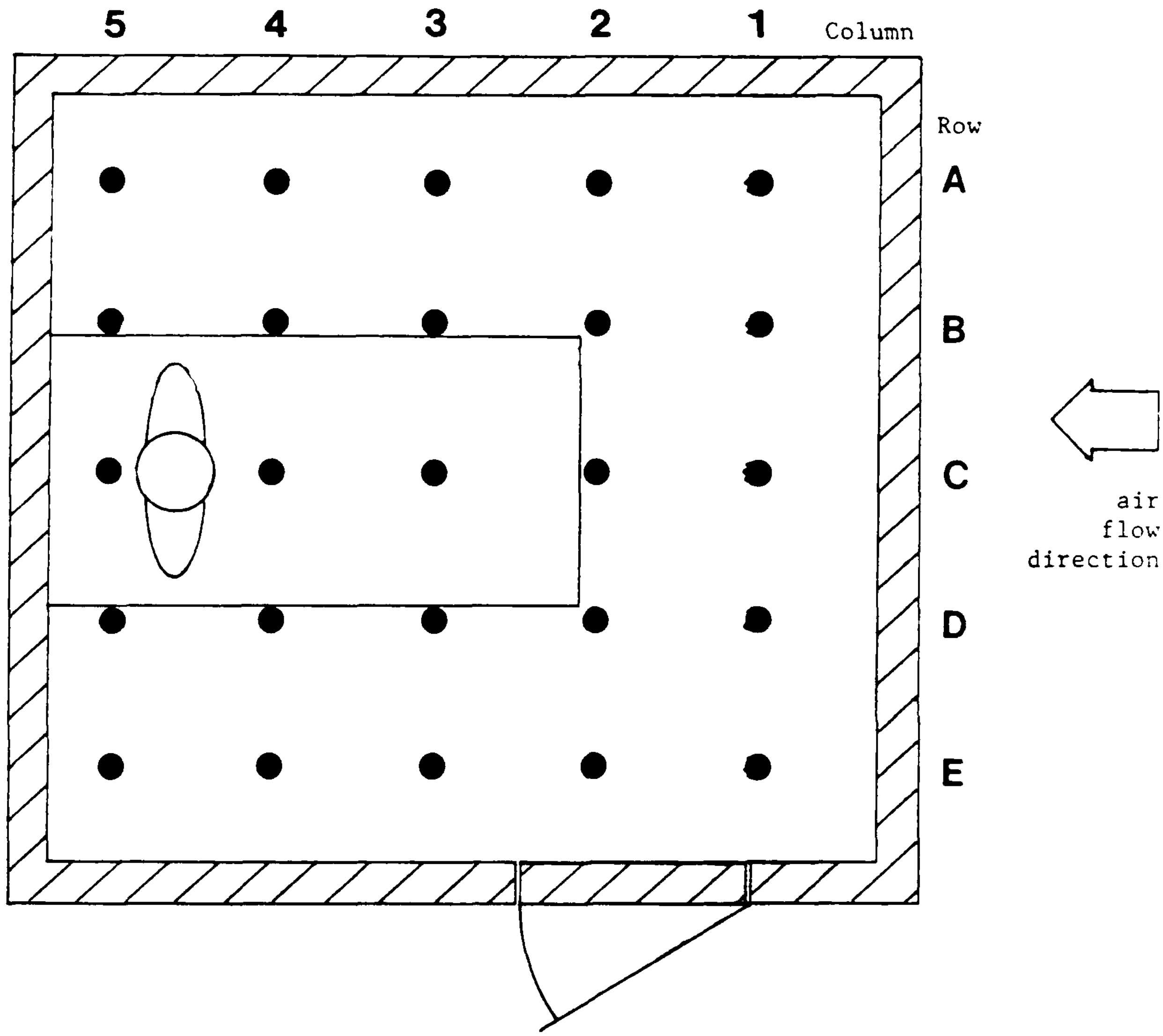

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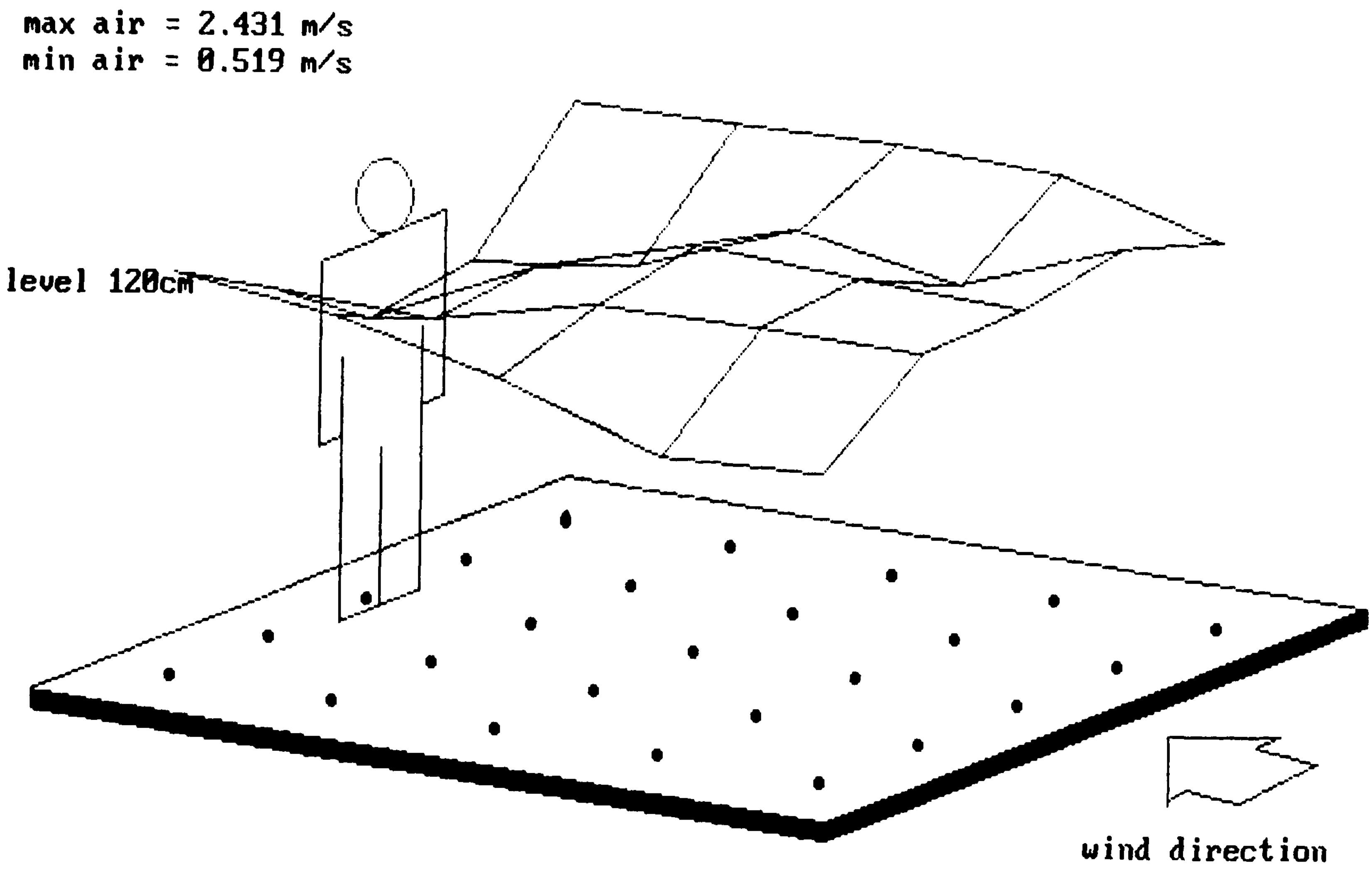

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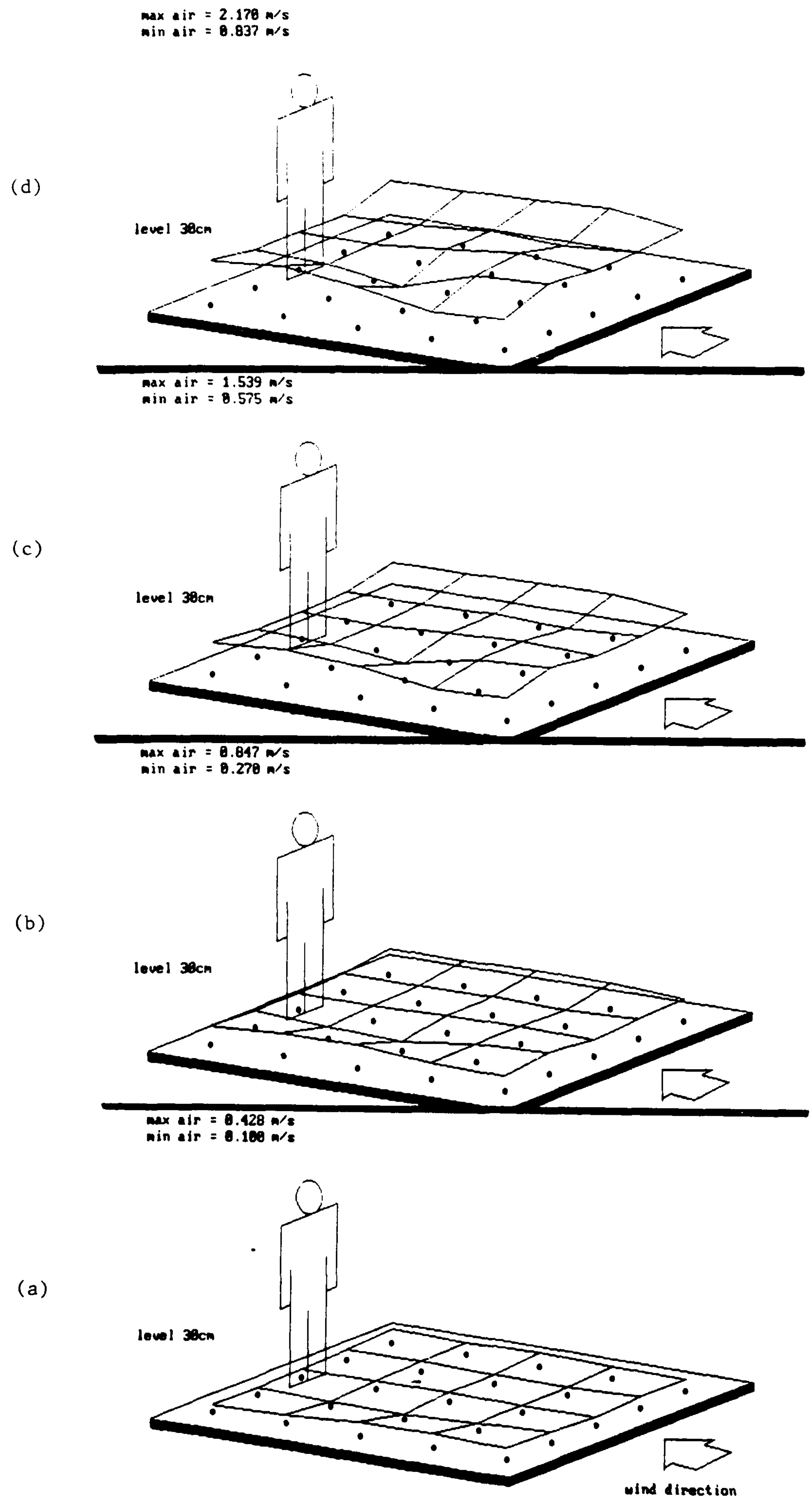
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min air = 0.837 m/s
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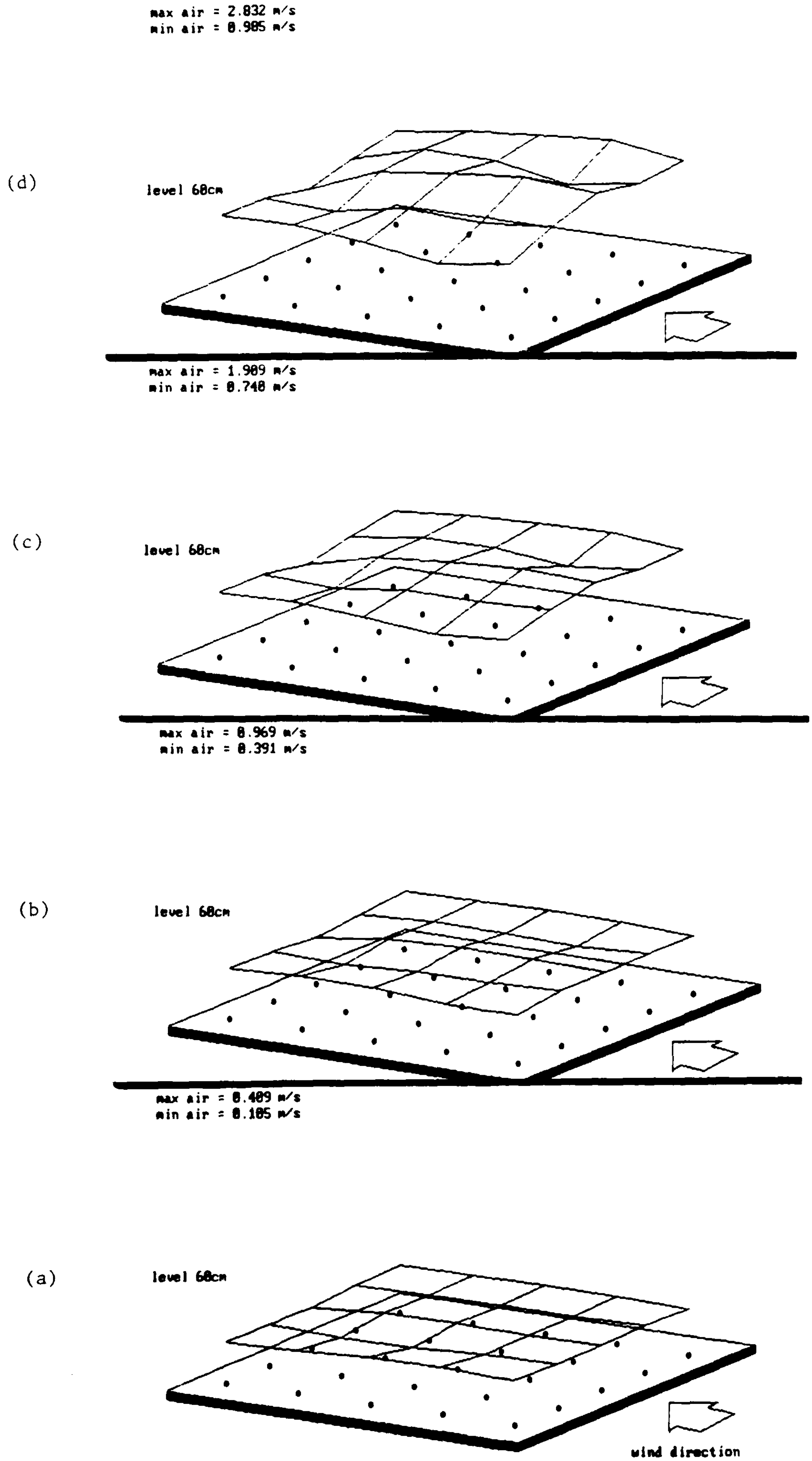
level 30cm
max air = 1.539 m/s
min air = 0.575 m/s
(c)
level 30cm
max air = 0.847 m/s
min air = 0.270 m/s
(b)
level 30cm
max air = 0.428 m/s
min air = 0.100 m/s
(a)
level 30cm
wind direction

Figure 5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level 60cm
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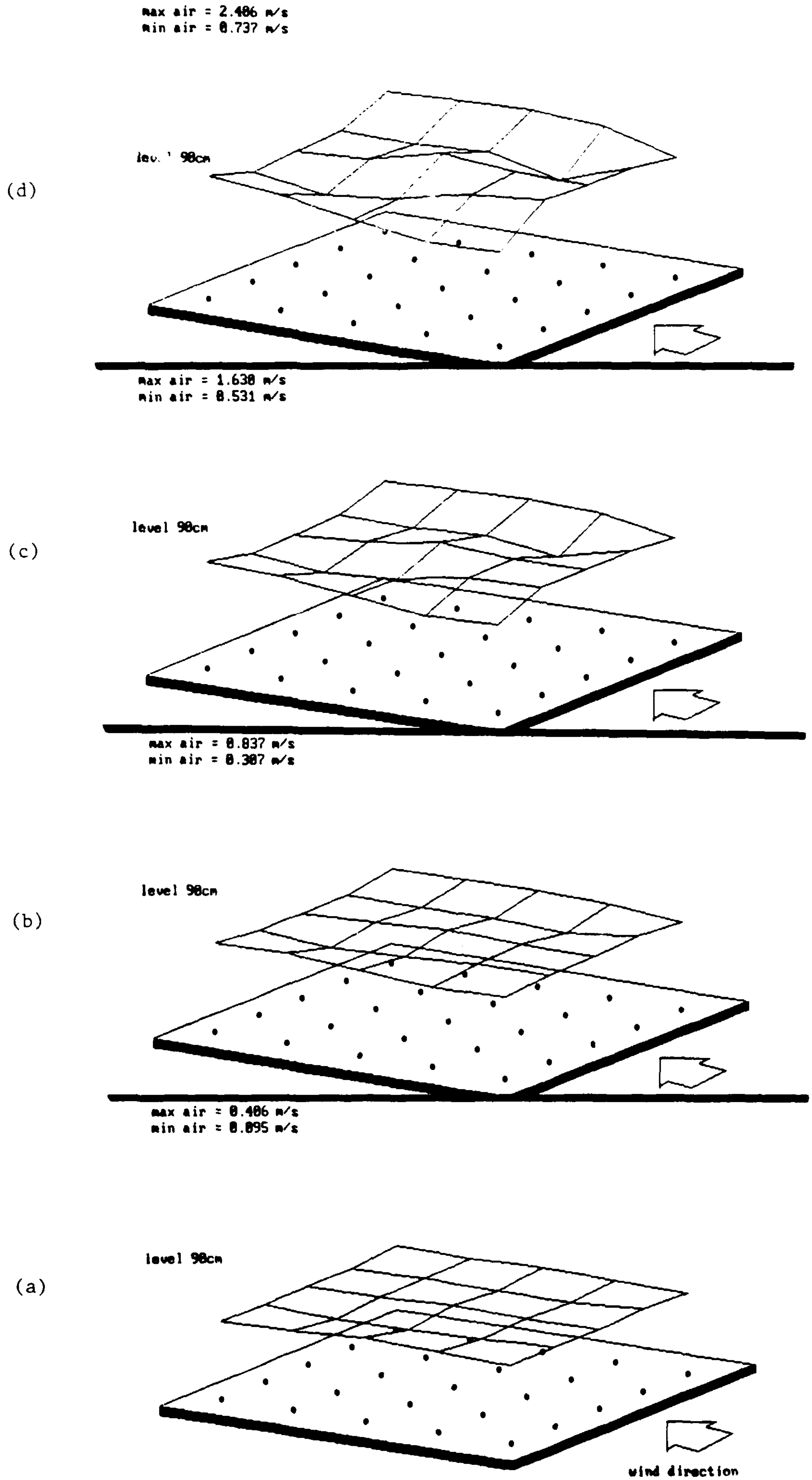
(c)
level 60cm
max air = 0.969 m/s
min air = 0.391 m/s
(b)
level 60cm
max air = 0.409 m/s
min air = 0.105 m/s
(a)
level 60cm
wind direction

Figure 6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(d)
lev. 90cm
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min air = 0.531 m/s
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level 90cm
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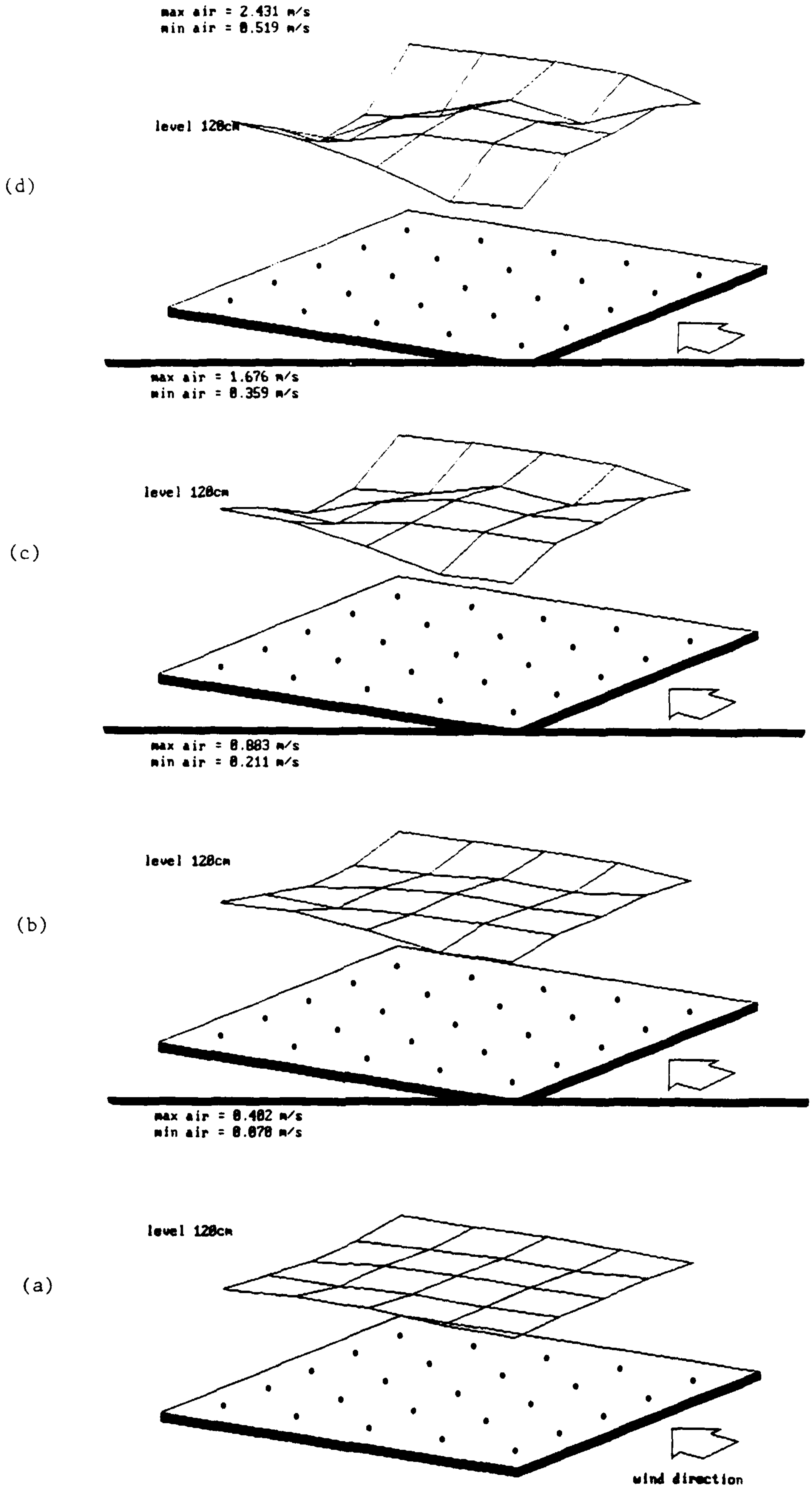
(a)
level 90cm
wind direction

Figure 7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level 120cm
(d)
max air = 1.676 m/s
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level 120cm
(c)
max air = 0.883 m/s
min air = 0.211 m/s
level 120cm
(b)
max air = 0.402 m/s
min air = 0.070 m/s
level 120cm
(a)
wind direction

Figure 8

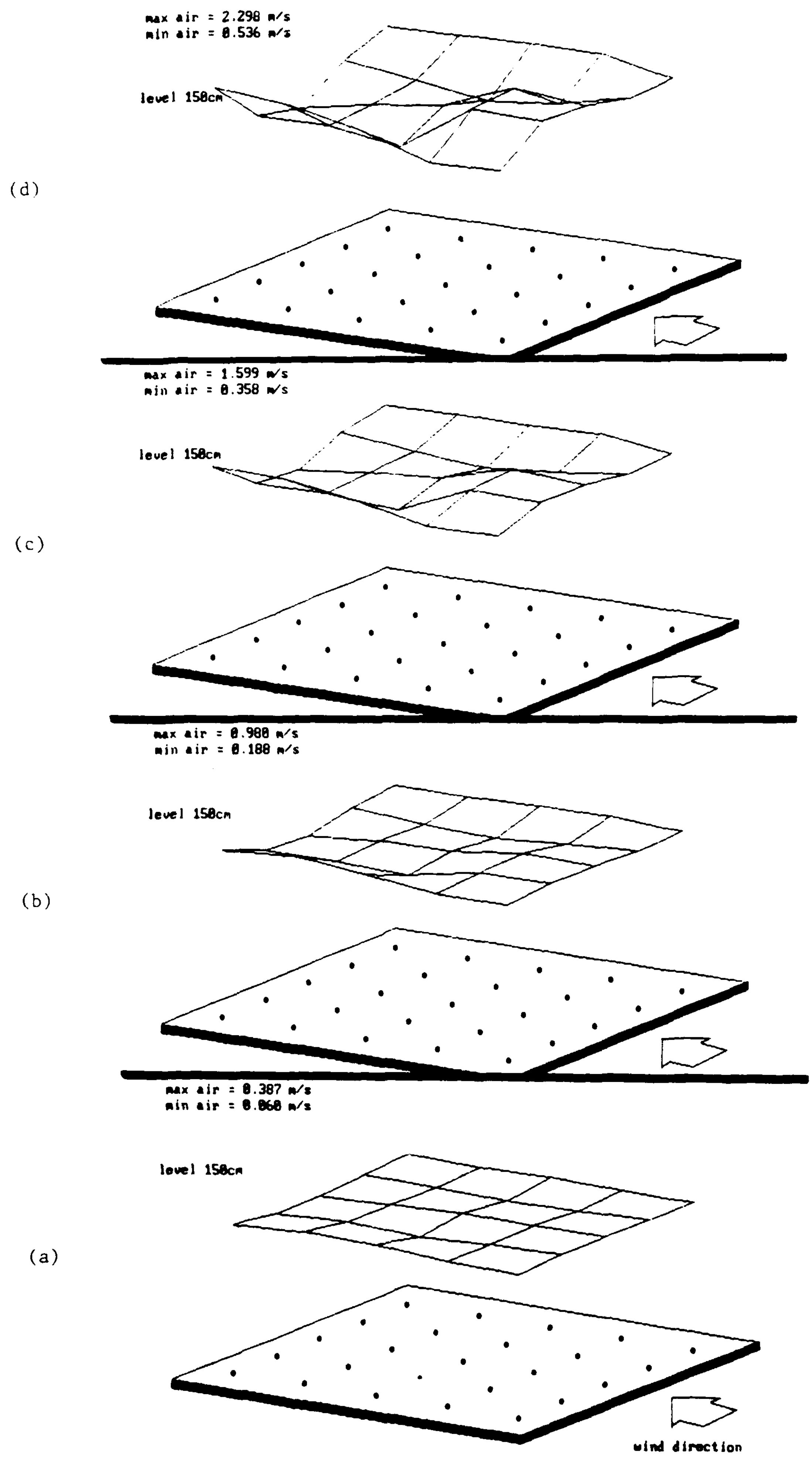
max air = 2.298 m/s
min air = 0.536 m/s
level 150cm
(d)
max air = 1.599 m/s
min air = 0.358 m/s
level 150cm
(c)
max air = 0.980 m/s
min air = 0.180 m/s
level 150cm
(b)
max air = 0.387 m/s
min air = 0.060 m/s
level 150cm
(a)
wind direction

Figure 9

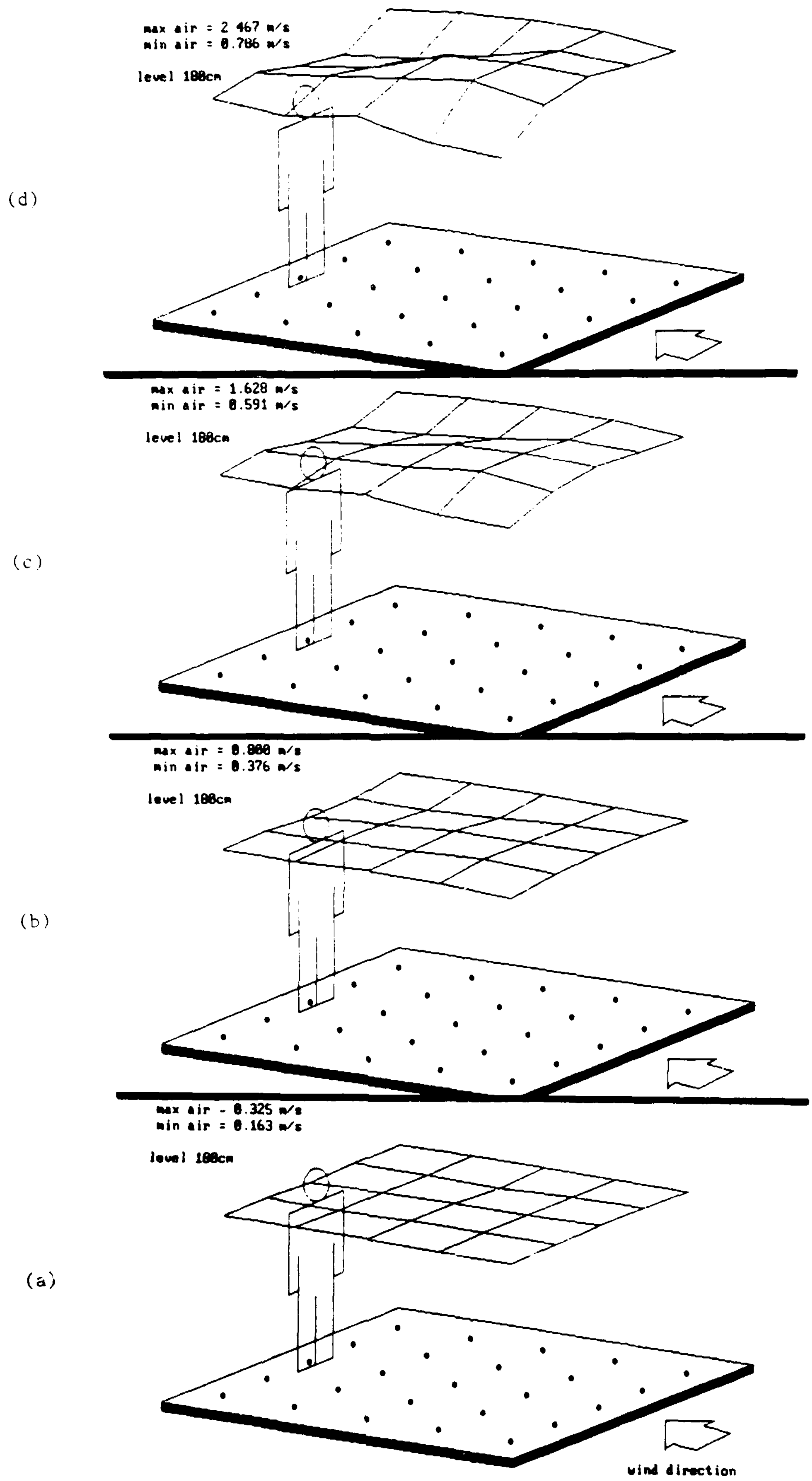
max air = 2 467 m/s
min air = 0.786 m/s
level 100cm
(d)
max air = 1.628 m/s
min air = 0.591 m/s
level 100cm
(c)
max air = 0.800 m/s
min air = 0.376 m/s
level 100cm
(b)
max air - 0.325 m/s
min air = 0.163 m/s
level 100cm
(a)
wind direction

Figure 10